Trip Distribution Modeling in Tokyo Bay based on AIS Data

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Abstract

In traffic modeling(1)(2)(3), a model is often assembled to simulate vessel streams within a designated traffic analysis zone, hereafter referred to as TAZ, such as harbors and straits. The traffic model usually consists of sub-models concerned respectively with traffic generation, and trip distribution(4).

In this paper, the underlying behavior and distribution of ships navigating from an Origin TAZ to a Destination TAZ are analyzed to assess the parameters behind the destination attribution based on the amount of the generated traffic at the origin. Then, the uncertainty associated and randomness with the traffic movements is estimated based on the concept of Entropy (5).

Keywords: trip distribution, traffic modeling, entropy, traffic simulation.

1. Introduction

Trip distribution analysis is the process by which ships sailing from one TAZ to another TAZ are analyzed. The trip distribution model is used to distribute the generated traffic from an Origin TAZ to a Destination TAZ. Compared to land traffic trip distribution analysis where many models are developed based on traffic purpose, route, and costs related to every destination, maritime traffic is constrained by the choice of the route, the destination based on vessel type and cargo type, and above all, the capacity of the TAZ.

2. Analysis Data

Tokyo Bay historical AIS data collected from the TUMSAT Advanced Navigation System, covering a period from the 11th of November 2011 to the 20th of November 2011, is used for this analysis.

3. Analysis Areas

Tokyo Bay, with its 1320 km², is selected as an analysis area. There are eight port areas in Tokyo Bay namely: Yokosuka Port, Yokohama Port, Kawasaki Port, Tokyo Port, Funabashi Port, Chiba Port, Anegasaki Port, and Kisarazu Port as shown in Fig. 1(a). Based on the port limits introduced above, nine TAZs are determined for this analysis as shown in Fig. 1(b).

1 TUMSAT: Tokyo University of Marine Science and Technology

Fig. 1 Illustration of Tokyo Bay Ports and Traffic Analysis Zones (TAZ) Limits

The defined TAZs are as follows:
1. Tokyo Bay Line TAZ: Area between the Tokyo Bay Line and Line “A”;
2. Yokosuka TAZ: Northern area of Yokosuka Port. The southern part is excluded from the analysis because of the ferry traffic and traffic around the Uraga Pilot Station which do not have any relevance to this analysis.
3. Yokohama TAZ: Area delimited by Yokohama...
4. **Research Method**

AIS destination data is one of the dynamic data that every ship should update after departure. All ships sailing into a port or in the vicinity of its boundary for the purpose of entering the port to which the Act on Port Regulation applies should enter the destination code designating the destination port in the column for information on destination as summarized in Table 1.

Table 1 AIS Codes for Tokyo Bay Port Destinations

<table>
<thead>
<tr>
<th>Port</th>
<th>AIS Destination code</th>
<th>Port</th>
<th>AIS Destination code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yokosuka Port</td>
<td>JP YOS</td>
<td>Funabashi Port</td>
<td>JP FNB</td>
</tr>
<tr>
<td>Yokohama Port</td>
<td>JP YOK</td>
<td>Chiba Port</td>
<td>JP CHB</td>
</tr>
<tr>
<td>Kawasaki Port</td>
<td>JP KWS</td>
<td>Anegasaki Port</td>
<td>JP ANE</td>
</tr>
<tr>
<td>Tokyo Port</td>
<td>JP TYO</td>
<td>Kisarazu Port</td>
<td>JP KZU</td>
</tr>
</tbody>
</table>

Following the above, port destination data is extracted from the AIS data. Unfortunately, the data is not accurate and the rate of non-compliance with the entry method is high. In addition, AIS data does not include the origin port necessary for our analysis. Due to this, it has been concluded that the AIS data is not suitable for extracting destinations and origins.

5. **Tracking Algorithm**

To solve the destination and origin issues described previously, an algorithm is developed to extract the Origin TAZ and Destination TAZ data from the ships’ tracks. The algorithm is built on the assumption that every ship sailing in Tokyo Bay has a start position where the ship appears on data screen, and an end position where the ship lays still in the water after berthing or anchoring. The algorithm tracks every ship sailing from one TAZ to another, and excludes any other ship that is not provided with an Origin TAZ and/or Destination TAZ. Fig. 2 shows the result of some trip analysis carried out for the AIS data on the 11th of November 2011. The red pushpins indicated the Origin TAZ, while the green pushpins indicate the Destination TAZ.

![Fig. 2 Illustration of the Origins and Destinations Tracking Algorithm](image)

6. **Trip Distribution Model**

Assuming $S$ is the number of ships calling the analyzed area and $N$ is the number of traffic analysis zones, ships departing from $TAZ_i$ are indexed as $A_i$ with a probability $u_i$, and ships arriving at $TAZ_j$ are indexed as $B_j$ with a probability $v_j$. Ships sailing from $TAZ_i$ to $TAZ_j$ are represented by $f_{ij}$ with a trip probability $\rho_{ij}$.

\[
\sum_i f_{ij} = A_i \\
\sum_i f_{ij} = B_j \\
\sum_j B_j = \sum_i A_i = S
\]

As for the probability of happening, it is defined as:

\[
\begin{align*}
\rho_{ij} &= \frac{f_{ij}}{S} \\
u_i &= \frac{A_i}{S} \\
v_j &= \frac{B_j}{S}
\end{align*}
\]

where:

\[
\begin{align*}
\sum_i u_i &= \sum_i v_i = \sum_{ij} \rho_{ij} = 1 \\
0 &\leq \rho_{ij} \leq 1
\end{align*}
\]
The uncertainty on the destination and origin can be reduced provided that the constraints imposed on every TAZ are known beforehand, such as the type of ships allowed, the maximum allowable dimensions, and allowable type of cargo. Unfortunately such information is not available, and so the uncertainty associated with the traffic movements is estimated based on the concept of Entropy. The Entropy \( H \) is defined as the uncertainty associated with the traffic distribution within a specific area, and it is related to the probability distribution of generated trips between the origin and destination. For the above mentioned trip distribution model, the Entropy \( H \) is defined as:

\[
H = - \sum_{ij} \rho_{ij} \ln(\rho_{ij})
\]

(6)

where:

\[
\begin{align*}
\rho_{ij} = 0 & \Rightarrow H = 0 \\
\rho_{ij} = 1 & \Rightarrow H = 0 \\
0 \leq \rho_{ij} \leq 1 & \Rightarrow H > 0
\end{align*}
\]

(7)

Entropy \( H \) is generally thought of as a metric of a system’s state of disorder as the higher a system’s entropy is, the more disordered the system is. And generally systems tend to move toward higher entropy values-- at which system stabilization is sought.

7. Results

Analysis results show that traffic originating from TAZ\(_i\) towards a destination TAZ\(_j\) where \(i=j\) accounts for a trip probability \( \rho = 0.34868 \). Fig. 3 shows two similar cases for Yokohama TAZ and Tokyo TAZ. The traffic between same TAZs is attributable to service boats, leisure passenger ships and the like.

Traffic trip distribution with a constraint, excluding trips within the TAZs, shows the conservation of traffic for every Origin and Destination TAZ respectively. In addition to trip combinations excluded by the constraint, 13 trip combinations are confirmed with certainty to be improbable.

Fig. 3 Illustration of Same TAZ Trips (Yokohama TAZ and Tokyo TAZ)

Fig. 4 Illustration of Traffic Generation and Attraction Distributions

Fig. 4 shows that the most attractive port is Yokohama Port and it alone generates and attracts more that 20% of traffic without constraint, and around 15% of traffic with constraint, of the total traffic in Tokyo Bay. Furthermore, the results show that around 70% of traffic without
constraint, and around 60% of traffic with constraint, originated from within Tokyo Bay.

8. Conclusion

This paper introduces a review of the Trip Distribution theory and its fundamentals. The Trip Distribution theory is then used to model vessel traffic streams navigating between different TAZs in Tokyo Bay based on AIS data.

In addition to the origin port which is not provided within the AIS data, a data review also reveals that the destination port provided within the AIS data is not accurate and the AIS data entry non-compliance rate is high. Therefore, to solve the destination and origin issues, an algorithm is developed to extract the Origin TAZ and Destination TAZ data from historical ships’ tracks. The algorithm tracks all ships sailing from one TAZ to another, and excludes any other ship that is not provided with an Origin TAZ and/or a Destination TAZ.

The results of the Trip Distributions analysis show that the traffic is conserved between every Origin and Destination TAZ respectively. In addition to trip combinations excluded by the constraint, 13 trip combinations are negated with certainty. In addition, the results also show that the most attractive port is Yokohama Port and it alone generates and receives more than 20% of traffic without constraint, and around 15% of traffic with constraint; of the total traffic in Tokyo Bay. Furthermore, the results show that around 70% of traffic without constraint, and around 60% of traffic with constraint; is originating from within Tokyo Bay.

The results of this paper provides an effective tool for evaluating the distribution of vessel traffic streams loads and appraising the level of disorder caused in Tokyo Bay. Furthermore, the model formalizes the trip distribution into a matrix that can be used as a metric for traffic generation and evaluating the fluctuation in traffic and/or TAZ traffic load assignment. Nevertheless, further research is needed to assess the traffic within the same TAZ by breaking-down every TAZ into Sub-TAZs.

9. References